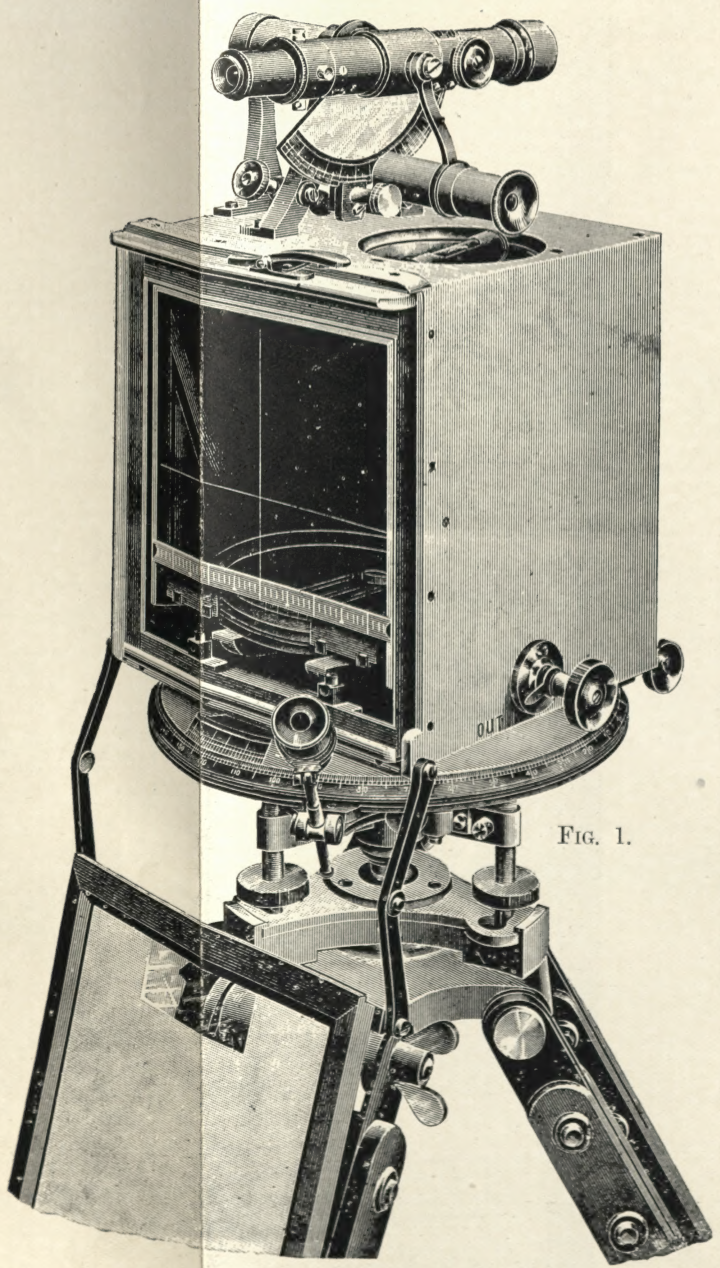

Fig. 1.

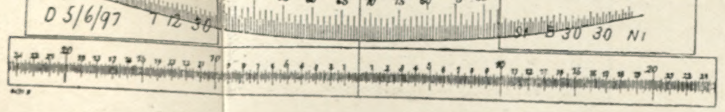

Fig. 2.

Fig. 3.

Fig. 4.

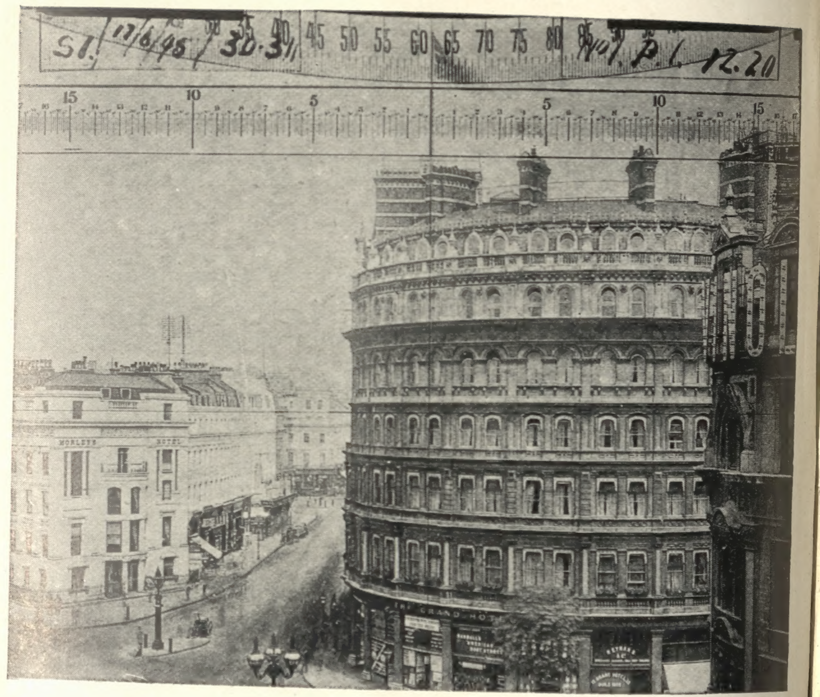

Fig. 5.

Fig. 6.

Fig. 7.

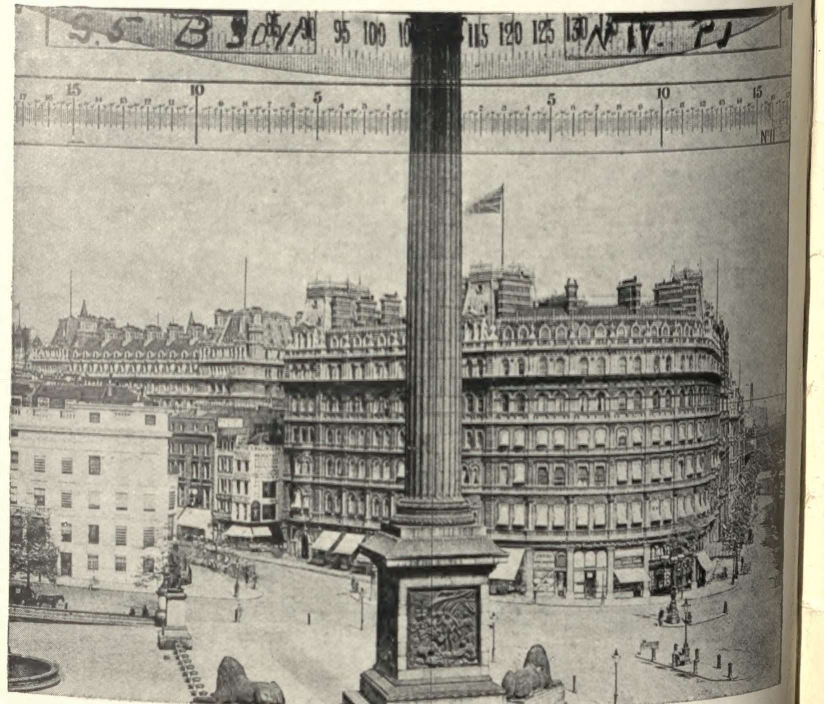

Fig. 8.

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JOHN CORRY FELL, President, in the Chair.

PHOTOGRAPHIC SURVEYING.

By J. Bridges Lee, M.A.

Introduction.

Since the earliest dawn of photography the possibility of making maps from photographs has been recognised, and from time to time detailed maps have been made with the aid of photographs, many of which are most accurate and excellent in every way. The earliest worker in this field was M. Laussedat, a French officer of Engineers, who before the dawn of practical photography had already studied the art of plotting topographical details from perspectives. Laussedat originally employed hand-made perspective sketches, and he designed a special improved form of camera lucida, and simple convenient means for mounting it, so as to obtain perspectives as free from errors as circumstances permitted.

His first experiments were made in 1849; his first paper on the subject was written in 1850 and published in 1854. The title of his original paper was 'Mémoire sur l'emploi de la chambre claire dans les reconnaissances topographiques.' Mémorial de l'officier du génie, No. 16, 1854. Afterwards, in 1859, a paper by Laussedat was published in the 'Comptes rendus de l'Académie des Sciences,' entitled "Analyse d'un mémoire sur l'emploi de la photographie dans le levé des plans." This was followed by a "Rapport sur le mémoire de M. Laussedat," by Langier and Daussy, published in the 'Comptes rendus de l'Académie des Sciences, 1860. In 1862, Paté discussed in print the "Application de la photographie à la topographie militaire." Then again, in 1864, there appeared another memoir by Laussedat, "Sur l'emploi de la photographie dans le levé des plans." Mémorial de l'officier du génie, No. 17 of 1864.

Since then quite a number of French, Italian, German, Austrian, American and Canadian engineers and surveyors, and

a few Englishmen, have worked at the subject, both experimentally and theoretically. The following are the names of some of the writers on the subject:—Jouart (1866), Javary (1874), Le Bon (1889), Mœssard (1889), Bomecque (1886), Legros (1892), Laussedat (1893–94), Monet (1894), Vallot (1897), Paganini (1889), Girard (1865), Meydenbauer) (1867), Jordan (1876), Hauck (1883) (1884), Stolze (1887), Reed (1888), Koppe (1889), Steiner (1891–93), Schiffner (1892), Meydenbauer (1892), Pollack (1893), Wang (1893) and Deville (1895). This list is by no means exhaustive. In recent years especially there have been numerous papers and articles and résumés of work done, and miscellaneous notes and notices appearing more or less in every part of the civilised world in various scientific technical and photographic publications, and the subject is now commencing to be systematically studied and taught in technical schools and colleges, and to be included in standard text-books on surveying. The total amount of literature on the subject is really very extensive, but unfortunately it is very much scattered and in many different languages.

The most complete practical treatise in the English language is a work by Mr. E. Deville, surveyor-general of Canada, entitled "Photographic Surveying," published at the Government Printing Bureau, Ottawa, 1895. The first small edition of that book was originally written in 1889, solely for the instruction and guidance of the Canadian surveyors, and the whole edition was exhausted in less than a year. The second larger edition of 1895 is, the author believes, now nearly exhausted. Meanwhile, the veteran Colonel Laussedat, who is now Directeur of the Conservatoire des Arts et Metiers in Paris, is now engaged on the completion of a great work in which he passes in review the whole history of surveying methods and apparatus from the earliest times to the present day, leading up to and describing the most recent developments of metrophotography, which he still believes to be the method of the future. The first volume only of that great work has yet been published. The second and final volume is in course of preparation.

The most recent illustrated comprehensive treatise on the subject is a Spanish work just published in Madrid, entitled "Topografia fotografica o sea aplication de la fotografia al levantamiento de planos," by C. de Iriarte, vocal de la Comision del mapa agronomica de España, and Professor L. Navarro. This is a work of 463 pages, with a supplementary book containing 26 sheets of illustrations which are 192 in number. Altogether this appears to be the most complete practical treatise on the subject which has been published up to date.

Of the many maps prepared by metrophotographic methods which have been published from time to time, some of the best have been published by the Canadian Government, where tens of thousands of square miles have been surveyed by photography in the north-west districts. There is also a considerable collection of good maps thus prepared, to be seen at the Conservatoire des Arts et Métiers in Paris, and a quantity of admirable detailed work has been done in central Europe (mostly in Alpine districts), especially by French, Italian and Austrian engineers.

For some years past MM. J. and H. Vallot, the founders of the observatory on Mont Blanc which bears their name, have been engaged on a very exact detailed re-survey of the Mont Blanc *massif* by photography, and the author believes that experimental, and in some cases moderately extensive work, is now going on in most parts of the globe. Still it must be admitted that in many quarters there is even now a prejudice against the wholesale adoption of photographic methods in substitution for or even as a supplementary aid to the older better-known surveying methods.

Causes of Tardy Development.

The reasons why metrophotography has not yet attained a position of universal popularity among surveyors are no doubt numerous. In the first place there is a vast amount of inertia and professional conservatism to be overcome. Men who have been trained from their youth upwards to use more familiar instruments and ordinary conventional methods of work, cannot be easily converted to a belief that it would be advantageous to substitute new methods with which they are not familiar for older methods with which they are so intimately acquainted. This difficulty is not of course peculiar to metrophotography any more than to any other proposed innovation of importance, except in so far as metrophotography is essentially a somewhat difficult subject to learn and to practice. This initial difficulty may be expected to vanish as new men come forward, who have been trained to apply the new methods, provided they can prove that the new methods yield equally accurate reliable results with much less expense. For the rest there are certain evident special reasons why the progress of metrophotography as a practical branch of applied science has been slow. The abnormal backwardness of England in particular is perhaps largely due to the fact that our climate is not generally favourable for far-seeing photographic views, and the whole country

had been pretty thoroughly surveyed before metrophotography was even thought of.

Difficulties and drawbacks of more general applicability may be referred to the following circumstances:—

1. In the early days of photography, before good dry plates were readily obtainable, there were many and serious difficulties in the way of obtaining good photographic views for surveying purposes.

2. Old-fashioned types of lenses could not be depended upon to yield true perspectives to cover any considerable angular range.

3. Perspective and descriptive geometry are essentially difficult subjects to master.

4. Specially constructed apparatus, which must be made with great care and accuracy, is absolutely necessary for obtaining the photographic perspectives. Until recent years there were no good suitable instruments purchasable. Nearly every worker has been obliged to design his own apparatus and to get it made at considerable and largely disproportionate cost.

5. The literature on the subject has been too much scattered and, to some extent, speculative and unpractical, or too intricate and difficult for every-day use, and until recent years there has been a dearth of text-books dealing especially with the subject.

6. A few prominent persons here and there, who have tried the method a little at odd times and failed to work it successfully, have exerted a strong discouraging influence.

7. Until the Canadians boldly adopted photographic methods on a large scale for government work and proved the efficiency, accuracy, rapidity and great economy of the method, there was not sufficient detailed information available to encourage surveyors to go in for metrophotography for large and important work.

8. The plane table with which metrophotography is mostly in competition is so simple and direct in theory and in practice, and its use is so easily learnt, that it is deservedly a most popular apparatus for topographical work.

9. Work in the field is generally more pleasant, and therefore more popular than office work, and there are some obvious advantages about filling in details while the objects themselves are in full view. A photograph rarely conveys to the mind ideas of relative distance at all comparable in point of accuracy to the mental estimations which result from direct views of the objects themselves under ordinary familiar conditions.

10. Individual surveyors are generally paid by salary, or for the time occupied, and provided they can work with reasonable expedition by familiar methods, they have often

no sufficient direct personal incentive to seek after more rapid methods.

11. There are those who doubt whether photographic surveys can be as accurate as plane-table surveys.

12. There are also those who think that points cannot be so easily identified on photographs as when the photographer has the ground under his eyes.

These are all the reasons the author can adduce as impeding the progress of phototopography as a practical subject, and he has thought it best to state them frankly in order that they may be considered and examined to see how far they ought to have weight in the future.

THE CAUSES OF HINDRANCE CRITICISED.

In criticising and replying to the foregoing reasons, it may be surmised that professional inertia can only be conquered by persistency, and by proof that the innovations advocated are really beneficial, and by the education of willing learners whose market value will eventually be proportional to the efficiency and rapidity with which they can do their work. The author will consider the reasons seriatim.

1. Good reliable dry plates of uniform quality can now be easily obtained. All necessary photographic operations are now comparatively simple, certain, and easy of performance, and the necessary photographic equipment to be taken into the field is no longer excessively cumbrous.

2. The best modern lenses yield perspectives which are mathematically true with scarcely any appreciable error over an angle of 45° or more.

3. No doubt perspective and descriptive geometry are really difficult subjects to learn thoroughly, and to apply practically to photographs, but in a general way there is very little need to invoke the aid of any intricate or puzzling constructions for plotting from photographs. The ordinary method for plotting ground plans from photographs by the method of intersections is simple in the extreme, and requires no special knowledge either of perspective or descriptive geometry. Similarly, the ordinary and best method for plotting contours, by noting the intersections of horizon planes with points previously plotted on the plan, needs no special knowledge. For the rest, though not ordinarily essential, it is advantageous now and again to apply geometrical constructions for the interpretation of individual photographs, or for the identification of points. The point which the author desires to emphasise is, that whatever may be the real or apparent difficulties attending a thorough study of

perspective and descriptive geometry, no one should allow himself to be dissuaded from taking up photographic surveying as a practical subject by imagining that it is first necessary to acquire a thorough knowledge of these subjects.

4. Certainly specially constructed apparatus is necessary, and it must be accurately made, but it need not be complicated or cumbrous, and should not of necessity be very costly if there were sufficient demand to encourage wholesale manufacture. All who have tried their hands at photographic surveying have recognised the necessity for having apparatus specially suited for the purpose. Ordinary photographic pictures obtained in the ordinary way by the ordinary cameras of commerce are practically useless for surveying purposes, except so far as they may serve as rough guides or substitutes for hand-sketches to help a man to fill in a few details roughly by estimation.

In order that a photograph may be of any real use for survey purposes it is absolutely necessary in the first place to know the conditions of projection. Commonly, plane projection is used, and nearly all, if not quite all, the best work everywhere has been done with plane projections. In constructing any surveying camera for plane projection on the ordinary flat glass plates of commerce, the first point to attend to is to secure that the plane of projection (i.e. the focal plane) is accurately perpendicular to the principal optic axis of the lens. This is an essential condition for practical work. Then the focal plane should be always at the same fixed distance from the lens; in other words, the camera must be what is commonly called a fixed-focus camera. Also there must be some means for accurately levelling the camera when set up on its stand. Levelling screws are generally used, and there must be accurately adjusted levels on the camera so mounted that, when the bubbles are in the middle of their runs, the principal axis of the lens is truly horizontal, and therefore the picture plane truly vertical. Also, there must be some marks or indices which can impress their images upon each picture taken, and which serve to indicate where the optical centre of the picture is to be found, and to assist in determining the directions of the traces of a horizontal plane containing the optic axis, and also the principal vertical plane. Pointers projecting from, or notches cut in the back frame of the camera, are generally used for this purpose. These are all the special conditions which are absolutely essential, except, of course, a good lens to yield true perspectives.

5, 6, 7. No special comment, criticism, or reply seem necessary on these points.

8. Quite true; but there are certain natural necessary limi-

tations to the use of the plane table, which is essentially a fine-weather instrument. The plane-table topographer must be able to spend plenty of time at each station where his table is set up if he aims at constructing an accurate detailed map, and he may find it necessary to revisit a station several or even many times, or to work from a great multiplicity of stations, to fix with precision a sufficient number of details. There are limits to the number of rays which can be drawn at any station without causing confusion, and the identification of points from a new station to which rays have been drawn at another station must often be difficult, not alone because of the changed aspect of the view, but largely because memory may fail to recall some of the details as viewed at the old station, even with the aid of such notes as are appropriated to the individual rays.

A plane-table topographer who only aims at plotting a moderate number of salient points by the method of intersections, and who sketches in most of his details from mere visual impressions gathered at his stations, may certainly succeed in producing a map rapidly, but the map will not be everywhere accurate in detail. If, on the other hand, he aims at producing a map full of detail, and accurate as regards every detail, he must spend a lot of time over it, and all that time must be put in on the spot. There are countries and places in the world where it would be impossible in practice to make accurate detailed maps on a plane table without so much difficulty and cost as to be quite prohibitive.

In the end, no matter how carefully a map is constructed on a plane table, and assuming that every point plotted is accurately in place, there must always remain faults of omission. All details cannot possibly be plotted, and whenever any kind of important engineering work is in contemplation, such as the laying out of a line of railway, or a canal, or a road, it is always necessary to go all over the ground again, and to make a new special survey, before even provisional plans can be submitted with any confidence. On the other hand, when once a photo-topographer has obtained a good and complete series of survey photographs which cover the ground from different known points of view, he is able to extract from his photographs at any time in office and at leisure any topographical details which are required to be known. He has all his landscape views in hand. He can place views from different stations side by side, and make direct comparisons without having to depend on memory. He can verify and correct his maps at any moment, and other men can check his conclusions from the same photographs.

In an hour or two, at any time, and without leaving his office, he can extract from the pictures topographical information

which could not be otherwise obtained without despatching expeditions, often at great cost, to retraverse the ground. Then again, phototopography is not really difficult or complicated in practice. Such special difficulties as there are are mainly connected with obtaining reliable apparatus, and so using it as to collect sufficient good reliable photographs. Given the photographs, and sufficient information about them (*vide* infra), it is a very easy and simple matter to plot from them. If good lantern slides are made from these photographs, and enlarged images projected upon vertical screens from appropriate spots over the plan, and in the proper directions corresponding exactly with the directions of view at the station points, it is possible to plane table upon those enlarged pictures just as might have been done in the field with the actual landscapes in view, with these very great advantages superadded that, (*a*) the operator is independent of the weather; (*b*) there need be little or no risk of confusing rays; and (*c*) generally the drawing of rays may be dispensed with, because plane tabling from two stations at once may go on simultaneously, and it is only necessary to plot straight away the points where the alidades intersect. This plan of operation has not yet come into use, and is subject to the drawbacks that special apparatus is required to work it and plenty of space, and work would have to be done by artificial light; but the ordinary methods for plotting from moderately enlarged photographs are almost equally simple, though not quite so direct.

It may be noted that phototopography may be used to supplement plane-table work. The competition between the two methods of working is more apparent than real. Both certainly are used for filling in details, but they may perfectly well be worked together; and survey pictures taken at plane-table stations would cost very little additional labour, and be most useful for helping to complete the survey.

9. Not much comment is needed here. Certainly a wide-angle photographic picture may tend to mislead those who try to estimate relative sizes and distances by simply looking at the picture. We are accustomed to scrutinise objects by direct vision under small visual angles, and, further, the photograph is a plane projection such as we do not ordinarily meet with under natural conditions; but knowing this, there is no reason why anyone should be actually misled.

10. Little, perhaps, need be said about this. No doubt in this, as in all other professions, there are a majority of men who take a very real interest in everything which relates to the practice of their profession, and it must be to the real advantage of all classes of workers to work with the most efficient tools.

11. Such doubts have no solid foundation. They are doubts

based upon speculative considerations at best, and have been proved to be unsound by the execution and publication of maps made from photographs which will bear favourable comparison with the best maps prepared by other methods.

12. Probably persons not accustomed to the close critical examination of photographs for the purpose of picking out points do experience this difficulty at first, but practice rapidly begets facility. Deville's remarks about this may be here quoted with advantage. He says, "Another objection is that points cannot be so easily identified on photographs, nor the forms of the surface so truly represented as when the topographer has the ground under his eyes. This is a mistaken idea; there is no difficulty whatever in identifying any number of points on moderately good photographs, and, moreover, the topographer does not need, as with the plane table, to trust to his memory in order to recognise them. The undulations of the ground are, it is true, less distinct on the photographs, but this is more than compensated by the advantage of having, side by side, views of the same place from several stations." With these remarks the author thoroughly agrees.

Special Advantages of the Photographic Method.

Having passed in review the chief causes which have operated to retard the progress of photographic surveying, the author will now enumerate a few of the special advantages of the photographic method in addition to what has been said already.

1. A complete set of photographic survey views of any area form a record of the topographical features of the ground more complete and reliable than can possibly be obtained by any other known means.

2. Half-an-hour or an hour of clear weather at a station will ordinarily suffice to obtain a number of plates sufficient to secure a complete set of views from that station. Often suitable stations for survey work may be so far away from the nearest sleeping place that they cannot be reached without considerable trouble and the expenditure of considerable time, and, being reached, it may be impossible for a topographer to stay there for any great length of time. A plane table could not be used at such places for any amount of detailed work, while it might be possible easily to obtain a full set of survey pictures.

3. In places where the weather is very unsettled, the camera can be used so as to take full advantage of short clear interludes, where plane-table work could only be carried on under great difficulty, if at all.

4. For military purposes, especially in an enemy's country, a surveying camera has pre-eminent advantages, because of the rapidity with which accurate topographical information can be gleaned, and because the photographs will yield information about elevations and undulations of ground, &c., besides furnishing information from which positions and distances can be determined.

5. A traveller making a rapid traverse through new or imperfectly surveyed country could only, by ordinary means, make at best a fragmentary route survey; but with a surveying camera he could, without any more trouble, collect photographic records from which a complete detailed survey of the route and of the country round could be made at leisure afterwards.

6. Wherever important geological or physiographical changes are known or believed to be in progress, the most satisfactory way to gather exact information of the nature and extent of those changes would be to compare survey photographs taken at intervals of time.

7. Whenever surveys are effected by any ordinary method, it would always be advantageous to obtain survey photographs from the station points of the ground surveyed, for all sorts of reasons—as, for example, to fill in details accidentally omitted or passed over for want of time at the spot, or to check the work done, or to supplement that work by way of pictorial illustration.

8. Many travellers are competent photographers who are not fully qualified surveyors. A very little training with the use of a surveying camera would enable such travellers in most cases to take photographs from which competent phototopographers could construct serviceable maps.

9. The photographic method of surveying is very much more economical than any other. Deville has shown that plane-table surveys in Canada would cost at least three times as much as the camera survey.

10. The principle of division of labour, with all its attendant advantages of increased efficiency and economy, is especially applicable to photographic surveying. A skilled phototopographer in charge of a survey can travel rapidly about the country to be surveyed with his camera and theodolite, and either with or without a specially skilled photographic assistant. He can select and fix the positions of his stations and expose his plates, which can then be made over to a skilled photographer to be developed, enlarged, printed, &c. After this the pictures can be passed on to assistants to make maps from, and the head topographer can exercise a general supervision over all.

11. When preliminary experimental surveys are required for irrigation purposes or for ascertaining the best routes for

roads or railways, very great economy will often result from using the photographic method, because it is generally impossible to foresee what amount of plotting will need to be done before a definite decision is arrived at.

Various kinds of Photogrammetric Apparatus.

The author will now pass in review the various kinds of photogrammetric apparatus which have been designed by different workers. Any attempt to describe in detail all the instruments which have been made would cause this paper to swell to the dimensions of a moderately large volume, but the leading distinctive features of the chief instruments which are mostly built up from a few fundamental types may be noticed with advantage.

The first point for attention is the kind of projection to be used for making the pictures. Theoretically, spherical projections would probably be best, if they were practicable. If we could obtain photographs on the inner surfaces of hollow spheres the optical centre of the photographic lens being at the centre of the sphere, then all angular distances between points in any positions would be simply proportional to the linear distances between these points measured along the surface of the sphere of projection, and this kind of image would approximate most nearly to the form of natural images formed on the retina of the human eye. Porro, a distinguished Italian engineer, did in fact, many years ago, propose the construction of a camera to receive spherical plates, but for obvious reasons, the idea was not practically workable, and it was never carried out.

Others have proposed to employ cylindrical projection, the axis of the cylinder being vertical. This idea has been applied for the production of panoramic pictures. and for purely pictorial purposes it has on occasions been found to produce fairly satisfactory results. Panoramic pictures obtained by cylindrical projection present a more natural appearance to the eye than would a number of plane pictures placed side by side in order, because equal linear distances measured horizontally along the horizon, represent approximately equal angular distances, but for surveying purposes cylindrical projection instruments are open to numerous objections, and cannot be regarded as practically workable for anything approaching accurate work. Nevertheless, the use of such instruments has been seriously proposed for survey purposes from time to time, notably by Lieutenant Reed in his book published in New York on Photography applied to Topography, and M. Mœssard in Paris, and afterwards Colonel Stewart in England, have designed instruments of this type, which have been constructed and tried.

Putting aside then spherical and cylindrical projections as demonstrably unpractical, we come to plane projection instruments, built up with more or less elaboration upon the fundamental simple type described earlier in this paper, i.e.—

1. A fixed-focus camera to take flat glass plates.
2. A good lens.
3. Levelling screws and levels to render the optic axis truly horizontal and the picture plane truly vertical.
4. Pointers or notches to mark on the picture points, which if joined by ruled lines will give traces of the horizon plane and of the principal plane of the perspective. The Canadian surveying cameras consist practically of nothing else except a deep orange light filter or colour screen of accurately plane glass, which fits over the lens, plus a kind of box sun-guard and cover-cap for the lens for ordinary cap exposure plus a primitive screw arrangement for forcing the plate tight against the back frame of the camera. The Canadian surveyors carry also theodolites as separate instruments and use them mainly for fixing with precision the exact positions of the camera stations. Instruments used by Meydenbauer, and Le Bon, and Werner, and others have been the same in principle though not always so solid, substantial and strong.
5. Most people who have designed photo-surveying instruments have added various accessory appliances outside the camera and built up more or less complicated instruments. For example, some kind of sighting arrangement is generally added, usually in the form of a telescope with cross webs to enable the optic axis of the lens (or rather the vertical plane which contains it) to be directed with precision towards any desired distant point.
6. The camera, with the structures which it supports, is commonly mounted on a vertical axis. It is always so mounted when there is a telescope.
7. Generally, also, there is a divided horizontal limb below the camera on which can be read the angle through which the instrument is rotated, plus clamps, verniers, microscopes, tangent screws, &c., as used on theodolites. These details are found in the instruments designed by Laussedat, Pollack, Stark and Kammerer, Vallot, Koppe, Rocha and others.
8. Sometimes, also, the telescope is fitted to a vertical limb to read vertical angles, so that the photogrammeter is in reality a surveying camera plus a theodolite.
9. Some instruments have rising and falling fronts with graduated scale, as those of Laussedat, Pollack, Rudolf, August Roost, Stark, and Kammerer. M.M. Vallot, instead of using a rising front to obtain vertical range, use several apertures at

different fixed levels, into any one of which the lens may be fitted as required. Deville relies on a moderately wide angle lens and a reversible box, which can be mounted with its greatest length either horizontal or vertical.

10. Sometimes the telescope is mounted at the side of the camera with its collimation axis horizontal, in the same horizontal plane with the optic axis of the photographic lens (Laussedat). Sometimes it is on the top of the camera (Huebl). Sometimes the photographic lens is used as the objective of a telescope, and a small eye-piece affixed to the middle of the ground-glass back (Pollack).

11. Laussedat's instrument is provided with a declinatoire.

12. Huebl's camera has a flat top, intended to be used as a plane table.

13. Rocha's photothodeolite is so mounted that the optical centre of the lens is in line with the vertical axis of revolution of the instrument. That instrument, like others which are unsymmetrical in construction, is provided with a counterpoise weight carried at the end of an arm (Pollack).

All these instruments, and a large majority of others, are intended to be used only with the principal axis of the lens horizontal, and the picture plane truly vertical. But there is yet another type of instrument designed so that it may be inclined vertically. Koppe's instrument, and also the phototheodolite of the Geographical Military Institute of Italy, are made on this principle. Instruments of this type require the very greatest possible care in use, and inasmuch as the picture planes may not only vary as regards their orientation (as with all other instruments), but also as regards their inclination to the horizon, the reduction of the photographs must often be really difficult. Nevertheless, most admirable maps have been made with the aid of these instruments. Paganini has recently designed a modified form of the original Italian instrument.

Lastly, although most people have used rectangular boxes, some use pyramidal, or wedge-shaped, or partially conical boxes, and thus save some weight (Paganini, Vallot, Laussedat, Koppe). Generally, the boxes of surveying cameras are made of metal, which is better than wood for the purpose, because there is less danger of its losing its shape and dimensions, and so throwing out the adjustments. Some people have used wood, or wood and brass (Laussedat), and a few have tried to use collapsing cameras, which could be held open at the fixed focal distance by metal bars or rods (Werner), but such instruments are manifestly very inferior.

All instruments previously referred to, and all others which

have been made before 1894, have this character in common, that the pictures which they yield are simply ordinary photographs with indicating marginal marks to show where the horizontal and the principal vertical lines terminate. The lines themselves are ruled across the picture afterwards by hand, and the point where they intersect is taken to be the principal point of the picture. Assuming there has been no distortion of the picture during manipulation, and assuming that the lines are quite accurately ruled from point to point the plan commonly adopted for marking the terminations and afterwards ruling the lines will yield accurate results. If, however, the picture has got distorted during manipulation, after the original exposure in the camera, these ruled lines will not represent the true traces of the horizon and principal planes. They may not intersect at the principal point and they will mislead the topographer.

The Author's Improvements.

1. In the first place it occurred to the author that it would be much better to produce those lines automatically and photographically at the moment of exposure in the camera, and for this purpose he uses two stretched human hairs fixed to the back frame of the camera in the focal plane, so that the plate is pressed close against them when in position, ready for exposure. The exact positions for attaching the ends of the hairs to the frame are marked by very fine slits and minute holes drilled in the frame, so that if a hair is at any time accidently broken it can be easily replaced by another, or if it gets slack it can be easily tightened.

The advantages which result from producing these lines automatically at the time of exposure are obvious. Time and trouble are saved, and if a photograph on which these lines have been thus produced gets distorted afterwards, the lines will get bent and betray the distortion and they can never mislead. These lines are absolutely essential for accurate effective interpretation of the photographs for measuring purposes, and it is chiefly because the true directions and intersections of the lines cannot ordinarily be ascertained from the examination of ordinary photographs not taken with a surveying camera, that such photographs cannot be made available for exact mapping purposes.

2. Again, it may be readily perceived that it is necessary to know the direction of the view before any effective use can be made of it for plotting. Generally this is ascertained

either from note-book entries made at the station, or it is deduced from the position on the picture of definite points whose true bearings from the station point are known.

When a topographer wants to plot from photographic views it is absolutely essential that those views should be correctly oriented before he begins to plot from them, and correct note-book entries or known points in the pictures suffice to enable him to orient his pictures correctly. But it has occurred to the author that an automatic record of the compass bearing of the optic axis or principal plane on the face of the picture would be of practical assistance for helping a topographer rapidly to select from a batch of photographs views looking in the desired directions, and also in many cases to help him to orient his pictures without loss of time. Accordingly the author places a good compass with a vertical cylindrical transparent divided scale inside the camera. The pivot point of the compass is in the same vertical plane which contains the principal optic axis of the lens, i.e. in the principal plane, so that the vertical hair serves as index for reading the compass bearing of the principal plane on the shadowgraph projection of the transparent scale.

There are many places in the world where the magnetic variation of the compass needle is approximately constant over considerable areas and the horizontal directive magnetic force strong. In such regions, with a well-constructed instrument fitted with this internal compass, ground plans may be plotted by reference only to the automatic compass records and the results will show very little error; but generally it is safest to use the compass records as guides to indicate the approximate directions of view, and to determine the exact directions with precision by reference to known land marks visible from the station when any exist. In every case it is convenient and useful to know the compass bearing of the view.

3. It is often desirable to be able to ascertain easily and at once the horizontal angle between some two points in a view, and it is always absolutely necessary to know the exact focal length of the lens with which the photographs have been taken; or, if the original photographs have been enlarged, then to know the equivalent focal length for each enlargement. It is impossible to plot from photographs by the graphic method until we know the correct lengths of the distance lines of the perspectives, that is, the focal distances of the picture planes.

Now photographs taken with any of the ordinary surveying cameras, or photogrammeters, or phototheodolites, &c., do not directly convey this information. It is quite impossible to

ascertain the horizontal angle between any two points in the picture without knowledge of the focal distance, and not always a very easy matter then without special constructions or computations, and if the focal length is not known *ab initio*, it may be a very difficult or, in certain cases, an impossible problem to ascertain it from an examination of the picture.

In order to simplify matters, and to render these determinations certain, quick and easy, the author prepares on a flat glass strip an exact scale of horizontal angular distances for each individual camera and lens, set exactly as they will be used for taking surveying pictures. The glass slip carrying the scale is let into the back frame with the scale face backwards, and exactly flush with the frame (i.e. in the picture plane), so that whenever a picture is taken with that instrument, the scale image will be impressed as a contact image upon the sensitive plate at the same time as the general picture, the horizontal and vertical lines, and the shadowgraph image of a portion of the compass scale.

The scale, as will be seen, prints itself as a contact print. It was prepared photographically in the picture plane. It prints its image in the picture plane on the negative, and will be reprinted as a positive on every print which may be made, and if either the negative or any print from it is enlarged or reduced, much or little, the scale will be enlarged or reduced in exactly the same proportion, so that every individual picture must always bear upon its face a true scale exactly appropriate to that particular picture. To ascertain the horizontal angular distance between any two points whose images appear in the photograph, it is only necessary to let fall perpendiculars from those points until they meet the scale, when the sum or difference of the scale readings will give at once the angle subtended at the station by those points. It is not necessary to rule the perpendiculars. A T-square or straight-edge will show the angle at a glance, and a fraction of a minute will suffice for such angular observation. Altogether the time required for reading horizontal angles or azimuths on the photographs will be very much less than would be consumed in reading the same angles with a theodolite in the field.

This scale also affords an immediate ready means for ascertaining the focal distance. If a table of natural sines, tangents, &c., is at hand, it is only necessary to measure off accurately any whole number of inches on the scale from zero, then note the angular reading at the distal end of the measured length, and multiply the number of inches measured by the value for the cotangent of the angle; the product will be the focal distance. Or the focal distance can be found by a very simple

the complement of

geometrical construction with a good protractor, thus:—Set off two lines at right angles to each other; measure off on one of these lines a distance equal to 15°, 20°, 25° or 30°, starting from zero; set off the angle at the end of the measured distance along one of the perpendiculars, and the length of the other perpendicular cut off by the line so set off with the protractor will be the focal distance.

4. In the last place the author acting further on the general principle that it is convenient to have ready to hand on the face of the picture itself as much useful or necessary information about it as possible, has designed a simple arrangement for impressing latent images of written memoranda at the same time as the picture itself and the other information automatically recorded. He uses narrow slips of celluloid, on which notes are written with ink. Such notes for example as the serial number of the picture, the station number, altitude of station or barometric pressure, date, time, &c. Letters and figures to notify these particulars are written on the strips and inserted upside down and face backwards in small hinged carriers specially constructed to hold them inside the camera. The memoranda are all made and the slips inserted before the dark slide carrying a sensitive plate is brought into operation. The notes being made on the slips and inserted before the picture is taken, the shadowgraphs of those notes will be impressed on the plate photographically at the same time as the picture itself.

The Author's Phototheodolite.

Figs. 1 and 2 of the illustrations are reproduced from 'Engineering.' Fig. 1 shows the general character and appearance of one of the instruments with which the author's name has been associated. The body of the camera is of aluminium alloy, fitted upon a theodolite base. Above it is a telescope and levels. In the most recent instruments the telescope is carried on Y's and is reversible, there is a complete vertical limb divided on silver, and there is a level on the telescope and a pair of levels at right angles to each other on the top of the box.

Inside the camera is a metal frame which slides in an antero-posterior direction on rails. The base of the frame carries a compass with a vertical cylindrical rim divided to half degrees from 0° to 360°. The pivot is attached to the base in the plane which bisects the instrument symmetrically, the compass rim passes in its revolution quite close to the vertical plane which corresponds to the outer face of the vertical skeleton frame which carries the hairs. This skeleton frame, which is designed

to carry the cross-hairs and tangent scale and also to secure that the picture plane shall be truly vertical, is connected with the base which carries the compass and is perpendicular to it. The tangent scale is prepared photographically by the same lens and in the same focal plane as used for taking survey pictures. The glass strip which carries the scale is let into the vertical frame, and is so fixed that the scale itself is flush with the picture plane, and will therefore yield a contact print on the picture plate when exposed. The zero line of the scale is in the principal vertical plane of the instrument. The frame also supports two carriers for the strips of celluloid for memoranda. The whole internal framework, with the compass, cross-hairs, tangent scale and hinged carriers which it supports, can be made to slide forward and backward by rack and pinion motion. The frame has no lateral or vertical play.

The internal fittings described can be applied to any good box camera, and it is not necessary, although it is convenient, to combine the camera with a theodolite. It is, however, always necessary to provide the camera with accurate levelling arrangements. Fig. 2 of the illustrations is a diagrammatic representation of the scales as they appear on all photographs taken.

Figs. 3 to 8 are reproductions of actual photographs taken with one of the author's instruments. Figs. 3, 4, and 5 are views from a point on the top of Drummond's Bank, overlooking Trafalgar Square, and Figs. 6, 7 and 8 are views from a point near the south front corner of the top of the Union Club. From these two sets of photographs it is possible to plot a large part of Trafalgar Square. To do this, it is only necessary to mark on a sheet of paper any two points in convenient positions near the bottom and left hand edges, and plot by methods to be described hereafter. The pictures are too small for very accurate plotting, but even from these small pictures, without enlargement, it will be found that the ground plan obtained of the square and buildings round will approximate closely to the Ordnance Survey map of the same ground.

There is only one other feature to which the author desires to direct attention, and that is the use of an optical screen of chromium green glass in preference to a deep orange screen. Everyone knows that distant landscape views are commonly obscured by a bluish haze in the finest weather. The light reflected by this blue haze is very highly actinic, and in consequence ordinary topographic views are often more obscured in the distance than natural views. In Canada, and other places where photographic surveys have been made, it has been the practice to use deep orange screens to intercept the most refrangible rays scattered by the blue haze. These screens are effective for the purpose for which they are used, but they

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prolong the period of exposure enormously, and exaggerate to an inordinate extent the natural contrasts of light and shade in the picture. Most orange-coloured glass obstructs light more or less from every region of the spectrum, while chromium-green glass—which is very highly transparent for all the middle regions from the yellow to the least refrangible blue—does not prolong exposure to anything like the same extent as the orange, and also does not develop such harsh, unnatural contrasts in the picture, while it is very fairly effective in subduing the obscuring effects of haze.

Field Work.

The author will now describe the method of conducting a photographic survey. Naturally, the first thing to do is to gather such general information about the country to be surveyed as is available at the time, and if the country has been partially surveyed to study and make use of the information already gained as a guide for further work. If a regular triangulation has been already effected over the area to be surveyed, the surveyor should provide himself with a plan, on which the triangulation points are accurately placed, or if there has been no previous triangulation then the exact positions of some of the principal points should be determined with great care by a preliminary triangulation whenever circumstances permit. The triangulation points will often be convenient camera stations, and more generally they will serve as reference data for fixing the exact positions of camera stations for assisting the topographer to correctly orient his photographs when he wants to plot from them, and for checking the accuracy of work in progress or completed. For the rest the same general principles which would guide a topographer in the selection of plane-table stations, apply to the selection of camera stations, except that he should take more careful account of the illumination of the landscape and the position of the sun.

The aim in all cases should be to obtain good clear views of all points which it may be desirable to plot on the map ultimately, and all such points should appear in views taken from two stations at least, and in such directions from those stations that the angle between the directions shall be neither too obtuse nor too acute. The photographic surveyor needs to be particularly careful to form correct mental estimates of the kind of intersections which his photographic views are capable of yielding, and he must never lose sight of the fact that while photographs from any particular pair of stations may perhaps yield perfect intersections for points in or near middle distance

from each station, they may yield only very acute intersections for distant points, or very obtuse intersections for near points. Cross views from any given pair of stations will only yield good intersections for plotting purposes within a definite area, which the surveyor in the field would ordinarily do well to shade off upon his skeleton plan in the field. For all points outside such defined and shaded areas other cross views from other stations are required. There should be a kind of scheme for the general location of camera stations within and around the area to be surveyed. The exact position of every station should be fixed with precision, and it is better to have views from an excessive number of stations rather than too few, but on the whole relative positions of the stations are more important than mere numbers.

The topographer in the field must continually bear in mind that the topographer in the office cannot possibly plot points which are not visible in the photographs, and he cannot obtain good intersections from cross views which would not have yielded good intersections in the field. The topographer in the office should check his work from time to time by reference to subsidiary photographs presenting points from third points of view, but the really essential matter for the field topographer to attend to is to make certain that his photographs shall yield one good intersection at least for every important point which may possibly need to be plotted.

The total number of views required at each station will not be excessive, and will depend largely upon the angle of view of the lens employed (i.e. on the ratio of the focal length of the lens to the size of plate) but the ultimate quality of the finished topographical work must depend very largely upon the good judgment of the field topographer in the selection of his stations.

Office Work.

The work done in the office consists firstly in the preparation of the photographs from the undeveloped plates exposed in the field, and secondly, in plotting from those photographs when ready for use. The plates should, of course, only be handled by a competent photographer who can be trusted to develop them to the best advantage. He must avoid subjecting the pictures at any stage to mechanical strains which might produce distortion of the images. The negatives or prints from them may then be handed over to the office topographer to work upon. It is possible to plot direct from photographs with only a 6-inch distance line, and to obtain fairly correct maps if very great care is taken over the plotting, but, as a rule, it is not

convenient to plot from short-focus pictures, and the maps are more difficult to plot and not so accurate when plotted as when enlargements are used.

There are several reasons for this. A short-focus picture, as before explained, does not yield correct impressions to the eye looking at it from a distance greater than the focal distance, and may therefore tend to mislead, and if thirty-five or more degrees of angle are included in a horizontal distance of some four or five inches measured along the picture, it is evident that five-minute intervals must be scarcely appreciable. Also with short-focus pictures only to work from, the traces of the picture planes will fall almost invariably within the area being plotted, which is not generally very convenient in practice. Suppose, however, that a 6-inch focus picture is enlarged 6 diameters; the distance line, or equivalent focus, becomes a yard, the picture presents a much more natural appearance to the eye at a moderate distance, and one-minute intervals are more easily appreciable than five-minute intervals were before, while the traces of the picture plane will ordinarily fall beyond that portion of the map which is being worked upon.

On the other hand, there is a limit to the amount of enlargement which is practically workable and convenient, and roughly speaking a distance line (or equivalent focus) of about a yard is somewhere near that limit. It is convenient that all pictures used for plotting should be enlarged to approximately the same extent, but although convenient, this is not strictly necessary, provided that the trace of the picture plane of every individual picture is drawn in its proper position on the plan.

The photographs having been handed over to the topographer in the office, the first thing he does is to critically examine them with the object of selecting a suitable pair of pictures, and a sufficient number of convenient salient points to plot. It must be assumed that the exact positions of the station points have been already plotted on the plan, and that every precaution has been taken to secure that those points are accurately plotted, because any error in the position of any station will vitiate nearly all results plotted from views taken at that station. It must be assumed, also, that besides having made sure of the positions of his station points, he has been able to select from the photographs at hand a suitable pair (one from each station) overlooking ground common to the two.

Having satisfied himself of the suitability of his pictures, he places them side by side, and proceeds to make fine red-ink dots on corresponding points in the two pictures, and writes in a small number, also in red ink, using the same number for the same point in each picture. This part of the work can be best

done by the person who originally traversed the ground and exposed the plates, because memory may help him with the identification of points.

Some people have complained of difficulty in identifying points in photographs, but Deville says:—"The identification of points, even under different lighting, does not offer any serious difficulties." In reality, it is generally easier to identify the same point on two photographs from different stations placed side by side, than it would be to identify the point in the field after moving from one station to the other; and even if any difficulty should be experienced by a beginner in identification upon the second picture, his difficulty can be surmounted by applying the elegant geometrical constructions of Professor Hauck, which will disclose the point if it really is visible in the second picture. Probably in many cases when people have not been able to recognise a corresponding point in a second picture, the real reason is that the point is hidden from view by some projection, and therefore not really visible at all. The golden rule about marking points on the survey photographs is never to mark anything we are not sure about. There will nearly always be plenty of points visible about which there can be no doubt at all.

Assuming that a number of points have been identified, marked, and numbered in each photograph, the next thing is to lay off on the plan, from the station points, the distance lines. These should be laid off with a good protractor, and great care should be taken that they are laid off in the right directions (i.e. correctly oriented). If the magnetic variation for the station is known, the true direction can be deduced from the compass bearing, or, better still, if there is any point visible in the picture whose true bearing is known, the angle between that point and the principal plane can be immediately ascertained by aid of the tangent scale of horizontal angles, and the true direction of the distance line can then be set off with great accuracy. That distance line is then prolonged until its length equals the equivalent focal distance for the picture, and a line accurately at right angles to the distance line is then drawn through the end of the distance line. This last line is the trace of the picture plane of the selected view from that station. The same operations are performed with regard to the other station and the other picture. The traces of the picture planes should be at least as long as the pictures are broad.

The topographer next takes two narrow parallel strips of paper as long as the pictures are broad. He then rules a fine line across the middle of each band, and taking one of the bands he marks off along one edge the exact distance of each

numbered dot on one of the pictures right and left of the middle line, and notes on the paper the appropriate number in close proximity to the dot. Having marked off on the band the respective distances of all the selected dotted and numbered points, he proceeds to transfer this strip of paper to the plan so that the edge carrying the dots shall coincide exactly with the trace of the picture plane, and the transverse line across the band be exactly in line with the distance line on the plan. The strip is then fixed in place, and he takes the other strip and proceeds in the same way with the other picture.

Both strips being now accurately in position with the lines of numbered dots along the picture lines, the next step is to drive small pins in the two station points. Then take two long fine threads of silk, make a loop at one end of each thread and slip that loop over the station pin. To the other end of each thread fasten a piece of elastic and to the end of the elastic fix a paper weight. Now shift the weights on the table or board (keeping the threads always sufficiently tight to mark straight lines) until the threads pass through dotted points bearing similar numbers on the two strips, taking care that the thread of each station covers the point on the picture line appropriate to that station. The intersection of the threads will be the position of the point on the plan. The threads really represent rays from the stations corresponding to rays which would have to be drawn on the plan of a plane-table survey. They do not need to be drawn for the photograph survey, because the topographer is working from both stations at the same time, and he can plot the intersections directly without incurring any risk of confusion among a number of construction lines.

All the selected points common to the two pictures can in this way be plotted in succession in an incredibly short space of time; and as each point is plotted the topographer will see whether he has a good intersection or not, and he can pencil-mark all points originally plotted from very acute or very obtuse angles, and check or, if necessary, alter the positions of those points when he can find better intersections for them from other stations. This process may be repeated indefinitely with other photographs from the same or other stations, and outlines between the plotted points can be filled in as the work progresses.

This is the method ordinarily employed in Canada and elsewhere for plotting ground plans by the graphic method, and experience has shown that with reasonable care and good judgment it yields thoroughly satisfactory results. It will be

noticed that there is nothing difficult or complicated about plotting by this method, and no special knowledge of perspective or descriptive geometry is necessary to apply it.

Contours.

With regard to contours, it may be noted that every horizon line on every picture bisects all points at the same level as the station points, and no others. It is evident, therefore, that if the positions of points along the horizon line are plotted on the plan, a contour line can be drawn at once by joining those points. It is evident that, in ordinary course, station points in hilly country are likely to be at various altitudes, so that without any special selection of stations for contouring purposes, a number of contour lines can be obtained from photographs taken at different stations. If special contours are required, the surveyor in the field should choose some stations at the particular levels for which contour lines are required to be traced.

These methods are at the same time the simplest and the best for obtaining plans and contours from photographs. Subsidiary instruments and methods may also be employed on occasions, such, for example, as the perspectograph for rapidly tracing a rough outline of the ground plan from a single photograph overlooking the ground; or a perspectometer, for quickly sketching in the outlines of lakes, or bays, or other flat surfaces; or a transparent protractor, for the direct reading of angles vertical and horizontal. Also, it is possible on occasions to plot portions of the ground plan from single photographs overlooking ground from a comparatively high angular altitude, by using vertical instead of horizontal intersections for fixing positions; but all such methods must be regarded as subsidiary only, and, as a rule, less accurate (though sometimes more rapid) than the ordinary methods described. Heights are best obtained by computation from the observed angular altitudes (referred to horizon lines whose altitudes are known) after the positions of the points on a plan have been definitely fixed.

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